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Air Pollution Aspects of Sludge Incineration

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Prepared for

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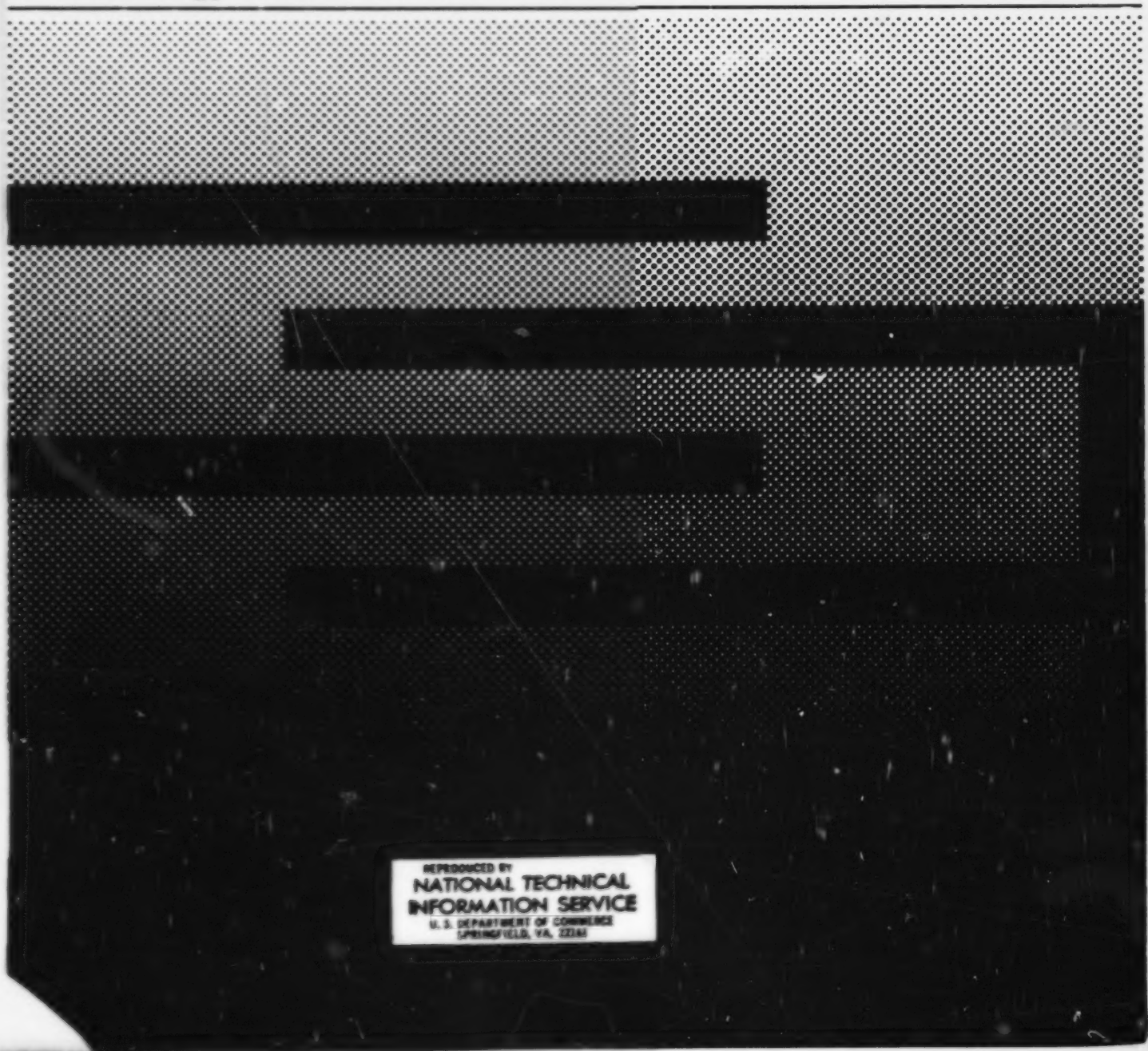

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Incineration offers the opportunity to reduce sludge to a sterile landfill and remove offensive factors, but it also has the potential to be a significant contributor to the air pollution problem in an urban community. This publication explains procedures that cope with the air pollution problems involved with sludge incineration.

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INTRODUCTION

Incineration offers the opportunity to reduce sludge to a sterile landfill and remove offensive odors, but it also has the potential to be a significant contributor to the air pollution problem in an urban community. The quantity and size of particulate emissions leaving the furnace of an incinerator vary widely, depending on such factors as the sludge being fired, operating procedures, and completeness of combustion. Incomplete combustion can form objectionable intermediate products, such as hydrocarbons and carbon monoxide. There is also the potential for discharge of air pollutants such as sulfur dioxide, nitrous oxides, and metals such as mercury.

PARTICULATE MATTER

New Source Performance Standards (NSPS) regulating discharges from municipal sludge incinerators have been promulgated by the Environmental Protection Agency (EPA). These standards limit the discharge of particulate matter from both new and modified sewage sludge incinerators. The process weight and opacity restrictions placed on this atmospheric pollution source are:[1]

- No more than 0.65 g/kg dry sludge input (1.30 lb/ton dry sludge input).
- Less than 20 percent opacity. Visible emissions caused solely by the presence of uncombined water are not subject to the opacity standard.

Available data indicate that, on the average, uncontrolled multiple-hearth incinerator gases contain about 0.6 grain of particulate per standard cubic foot of dry gas.[2] Uncontrolled fluid-bed reactor gases contain about 1.0 grain of particulate per standard cubic foot.[3] For average municipal wastewater sludge, these uncontrolled pollutant concentrations correspond to about 33 pounds of particulates per ton of sludge burned in a multiple hearth, and about 45 pounds of particulates per ton of sludge burned in a fluid-bed incinerator. Particulate collection efficiencies of 96 to 97 percent are required to meet the NSPS,[4] based on the above uncontrolled emission rate.

Sludge incinerators differ from most other types of incinerators in that the sludge does not normally supply enough heat to sustain combustion. Furthermore, there is less emphasis on retaining ash in the incinerator and much of it is discharged in stack gases. Particulate emissions to the atmosphere are almost entirely a function of the scrubber efficiency and are only minimally affected by incinerator conditions. Sludge incinerators in the United States are equipped with scrubbers of varying efficiency. These scrubbers range from simple spray-tower-type units to venturi-type scrubbers with pressure drops up to 40 inches of water.

Existing State or local regulations in the United States tend to regulate sludge incinerator emissions through incinerator codes or process weight regulations.[5] Many State and local standards are

Table 1.—*Sludge incinerator facility A_1: Summary of results*

Item	Run number			Average
	1	2	3	
Date	1-11-72	1-12-72	1-12-72	
Test time, minutes	108	108	108	108
Furnace feed rate, ton/h dry solids	0.550	0.560	0.560	0.557
Stack effluent:				
Flow rate, dscfm	2,880	2,550	2,660	2,700
Flow rate, dscf/ton feed	314,000	273,000	285,000	291,000
Temperature, °F	59	59	59	59
Water vapor, volume %	1.93	1.92	2.23	2.03
CO_2, volume % dry	12.8	12.6	11.5	12.3
O_2, volume % dry	4.8	4.7	6.4	5.3
CO, volume % dry	0	0	0	0
SO_2 emissions, ppm	<0.3	<0.3	<0.3	<0.3
NO_x emissions, ppm	4.2	5.7	6.4	5.4
HCl emissions, ppm	<3.8	<2.9	<4.1	<3.6
Visible emissions, % opacity	<10	<10	<10	<10
Particulate emissions:				
Probe and filter catch:				
gr/dscf	0.024	0.005	0.004	0.011
gr/acf	0.023	0.005	0.004	0.011
lb/h	0.583	0.116	0.099	0.266
lb/ton of feed	1.06	0.207	0.177	0.481
Total catch:				
gr/dscf	0.032	0.007	0.010	0.0163
gr/acf	0.031	0.007	0.010	0.016
lb/h	0.779	0.160	0.227	0.389
lb/ton of feed	1.42	0.286	0.405	0.704

Note.—dscfm indicates dry standard cubic feet per minute, dscf indicates dry standard cubic feet, acf indicates actual cubic feet.

Source: *Background Information for Proposed New Source Performance Standards*, EPA Report APTD-13526, June 1973, vol. 2, appendix.

corrected to a reference base of 12 percent carbon dioxide or 6 percent oxygen. Corrections to CO_2 or O_2 baselines are not directly related to the sludge incineration rate, because of the high percentage of auxiliary fuel required. In some regulations, the CO_2 from fuel burning is subtracted from the total when determining compliance.

Table 2.—*Sludge incinerator facility A_2—Summary of results*

Item	Run number			Average
	1	2	3	
Date	5-3-71	5-4-71	5-4-71	
Test time, minutes	60	60	60	60
Furnace feed rate, ton/h dry solids	0.325	0.325	0.325	0.325
Stack effluent:				
Flow rate, dscfm	3,480	3,600	3,320	3,470
Flow rate, dscf/ton feed	642,500	664,600	612,900	640,600
Temperature, °F	80	80	78	79
Water vapor, volume %	3.4	3.4	3.4	3.4
CO_2, volume % dry (less auxiliary fuel)	4.0	5.1	4.0	4.4
SO_2 emissions[1]	–	–	–	–
Visible emissions, Ringelmann No.[2]	<1	<1	<1	<1
Particulate emissions, total catch:				
gr/dscf (corresponds to 12% CO_2)	0.020	0.031	0.048	0.033
gr/acf	0.019	0.029	0.047	0.032
lb/h	0.596	0.956	1.365	0.972
lb/ton of feed	1.84	2.94	4.20	2.99

[1]No SO_2 detected.
[2]Opacity was not recorded.

Note.—Tested by local agency using code method 1. Probe and filter catch not analyzed separately. dscfm indicates dry standard cubic feet per minute; dscf indicates dry standard cubic feet; acf indicates actual cubic feet.

Source: *Background Information for Proposed New Source Performance Standards*, EPA Report APTD-13526, June 1973, vol. 2, appendix.

In developing the foregoing NSPS, tests were conducted on the gaseous discharges from several sludge incinerators. Stack tests were conducted by EPA at five locations, including three multiple-hearth incinerators and two fluid-bed reactors, as follows:[6]

A. Fluidized-bed reactor, 1,100 lb/h dry solids design capacity, operated at 100 percent capacity during test, equipped with a 20-inch-water-pressure-drop venturi scrubber operated at 18 inches water pressure drop. Tested by EPA and by a State agency, the latter using code method 8 (see tables 1 and 2).

B. Multiple-hearth (six hearths) incinerator, 750 lb/h dry solids design capacity, operated at 64 percent capacity during test, equipped with a 6-inch-water-pressure-drop single-crossflow perforated-plate impinjet scrubber (see table 3).

C. Multiple-hearth (six hearths) incinerator, 900 lb/h dry solids design capacity, operated at 35 percent capacity during test, equipped with a 6-inch-water-pressure-drop single-crossflow perforated-plate impinjet scrubber (see table 4).

Table 3.—*Sludge incinerator facility B Summary of results*

Item	Run number			Average
	1	2	3	
Date	10-13-71	10-14-71	10-14-71	
Test time, minutes	120	120	120	120
Furnace feed rate, tons/h dry solids	0.237	0.236	0.249	0.241
Stack effluent:				
Flow rate, dscfm	3,300	2,950	2,120	2,790
Flow rate, dscf/ton feed	835,000	750,000	511,000	699,000
Temperature, °F	198	196	199	198
Water vapor, volume %	3.64	4.02	3.65	3.77
CO_2, volume % dry	3.8	4.7	2.7	3.7
O_2, volume % dry	17.3	1.40	15.8	15.7
CO, volume % dry	0	0	0	0
SO_2 emissions, ppm	2.29 to 2.57	2.75	–	2.53
NO_x emissions, ppm	–	–	44.2 to 24.3 14.3	27.6
HCl emissions, ppm	–	–	0.624 to 1.33 0.621	0.858
Visible emissions, % opacity	<10	<10	<10	<10
Particulate emissions:				
Probe and filter catch:				
gr/dscf	0.0245	0.0196	0.0173	0.0205
gr/acf	0.0187	0.0155	0.0132	0.0158
lb/h	0.690	0.495	0.315	0.500
lb/ton of feed	2.91	2.10	1.26	2.09
Total catch:				
gr/dscf	0.0374	0.0374	0.0457	0.0402
gr/acf	0.0289	0.0287	0.0348	0.0308
lb/h	1.06	0.945	0.832	0.946
lb/ton of feed	4.47	4.00	3.34	3.94

Note.—dscfm indicates dry standard cubic feet per minute, dscf indicates dry standard cubic feet, acf indicates actual cubic feet.

Source: *Background Information for Proposed New Source Performance Standards*, EPA Report APTD-13526, June 1973, vol. 2, appendix.

D. Fluidized-bed reactor, 500 lb/h dry solids design capacity, operated at 95 percent capacity during test, equipped with a 4-inch-water-pressure-drop single-crossflow perforated-plate impinjet scrubber (see table 5).

E. Multiple-hearth incinerator, 2,500 lb/h dry solids design capacity, operated at about 50 percent capacity during tests, equipped with a 2.5-inch-water-pressure-drop cyclonic inertial jet scrubber (see table 6).

Table 4.—*Sludge incinerator facility C: Summary of results*

Item	Run number			Average
	1	2	3	
Date	7-15-71	7-15-71	7-16-71	
Test time, minutes	80	80	80	80
Furnace feed rate, tons/h dry solids	0.111	0.149	0.146	0.135
Stack effluent:				
Flow rate, dscfm	1,230	1,490	1,400	1,373
Flow rate, dscf/ton feed	665,000	600,000	575,000	613,000
Temperature, °F	80	80	77	79
Water vapor, volume %	3.23	3.00	2.95	3.06
CO_2, volume % dry	10.0	10.1	10.2	10.1
O_2, volume % dry	7.7	7.3	7.4	7.5
CO, volume % dry	0	0	0	0
SO_2 emissions, ppm	15.9 to 11.9	14.5 to 14.6	14.6 to 13.3	14.2
NO_x emissions, ppm	402 to 140	90.8 to 74.3	14.5 to 142 50.6 to 61.8	163
HCl emissions, ppm	3.50 to 2.62	2.33 to 2.62	2.52 to 2.62	2.72
Visible emissions, % opacity	<10	<10	<10	<10
Particulate emissions:				
Probe and filter catch:				
gr/dscf	0.0127	0.0620	0.0196	0.0314
gr/acf	0.00985	0.0477	0.0152	0.0242
lb/h	0.127	0.620	0.196	0.314
lb/ton of feed	1.14	4.16	1.34	2.21
Total catch:				
gr/dscf	0.0195	0.0696	0.0260	0.0384
gr/acf	0.0150	0.0535	0.0201	0.0295
lb/h	0.206	0.889	0.312	0.469
lb/ton of feed	1.86	5.97	2.14	3.23

Note.—dscfm indicates dry standard cubic feet per minute, dscf indicates dry standard cubic feet, acf indicates actual cubic feet.

Source: *Background Information for Proposed New Source Performance Standards*, EPA Report APTD-13526, June 1973, vol. 2, appendix.

The results of these tests are shown in tables 1 to 6. Figure 1 summarizes the results of the particulate measurements. The results from the unit using a venturi scrubber operating at 18-inch water pressure drop were used as the basis for the standard. The other systems using other types of scrubbers operating at lower pressure drops failed to meet the promulgated NSPS of 1.3 lb/ton dry sludge input. The study of these facilities indicated no relationship between the mass emission rates and the percent of rated capacity at which the incinerator was operating, but a strong relationship between pressure drop across the scrubber and mass emission rates was found.[4] All of the systems easily met the opacity standard. Observations at 15 other facilities indicated they all met a 10-percent

Table 5.—*Sludge incinerator facility D: Summary of results*

Item	Run number			Average
	1	2	3	
Date	7-21-71	7-21-71	7-22-71	
Test time, minutes	120	96	96	104
Furnace feed rate, tons/h dry solids	0.255	0.237	0.202	0.231
Stack effluent:				
Flow rate, dscfm	1,190	1,170	1,240	1,200
Flow rate, dscf/ton feed	280,000	296,000	368,000	315,000
Temperature, °F	99	99	95	98
Water vapor, volume %	3.92	4.90	3.48	3.83
CO_2, volume % dry	8.8	9.9	9.1	9.3
O_2, volume % dry	6.3	7.4	8.2	7.3
CO, volume % dry	0	0	0	0
SO_2 emissions, ppm	8.29 to 11.2	14.8 to 14.8	14.2 to 15.4	13.8
			17.8	
NO_x emissions, ppm	154 to 168	41.2 to 42.9	187 to 170	132
			161	
HCl emissions, ppm	0.780 to 260	4.16 to 1.56	2.35 to 2.09	2.26
Visible emission, % opacity	<10	<10	<10	<10
Particulate emissions:				
Probe and filter catch:				
gr/dscf	0.0551	0.0766	0.0545	0.0621
gr/acf	0.0468	0.0650	0.0467	0.0528
lb/h	0.562	0.768	0.579	0.636
lb/ton of feed	2.20	3.24	2.87	2.77
Total catch:				
gr/dscf	0.0665	0.0859	0.0653	0.0726
gr/acf	0.0565	0.0729	0.0559	0.0618
lb/h	0.678	0.861	0.694	0.744
lb/ton of feed	2.66	3.63	3.43	3.24

Note.—dscfm indicates dry standard cubic feet per minute; dscf indicates dry standard cubic feet; acf indicates actual cubic feet.

Source: *Background Information for Proposed New Source Performance Standards*, EPA Report APTD-13526, June 1973, vol. 2, appendix.

opacity. The estimated costs of the scrubbing systems used as standard practice in the United States are typically about 4 percent of the total incineration facility for a plant serving 100,000 people. The scrubber required to achieve the proposed particulate standards would increase the cost an estimated 0.4 percent. Annual operating costs were estimated to be increased by 0.9 percent.[5]

Table 6.–*Sludge incinerator facility E: Summary of results*

Item	Run number			Average
	1	2	3	
Date	8-5-71	8-5-71	8-5-71	
Test time, minutes	96	96	96	96
Furnace feed rate, tons/h dry solids	0.689	0.855	0.290	0.611
Stack effluent:				
Flow rate, dscfm	9,840	8,510	10,290	9,547
Flow rate, dscf/ton feed	–	–	–	–
Temperature, °F	135	145	145	142
Water vapor, volume %	16.3	18.6	14.8	16.6
CO_2, volume % dry	4.2	4.3	2.2	3.6
O_2, volume % dry	14.9	14.9	16.9	15.6
CO, volume % dry	0	0	0	0
SO_2 emissions, ppm	2.01	2.07	2.12	2.07
NO_x emissions, ppm	62.8 to 46.0	93.5 to 75.8	44.3 to 54.7	61.2
HCl emissions, ppm	11.9	6.83	10.9	9.88
Visible emissions, % opacity	<10	<10	<10	<10
Particulate emissions:				
Probe and filter catch:				
gr/dsf	0.0260	0.0136	0.0134	0.0177
gr/acf	0.0196	0.0099	0.0101	0.0132
lb/h	2.19	0.99	1.18	1.45
lb/ton of feed	3.18	1.16	4.07	2.80
Total catch:				
gr/dscf	0.0335	0.0221	0.0170	0.0242
gr/acf	0.0252	0.0159	0.0128	0.180
lb/h	2.83	1.61	1.50	1.98
lb/ton of feed	4.11	1.88	5.17	3.72

Note.–dscfm indicates dry standard cubic feet per minute; dscf indicates dry standard cubic feet; acf indicates actual cubic feet.

Source: *Background Information for Proposed New Source Performance Standards*, EPA Report APTD-13526, June 1973, vol. 2, appendix.

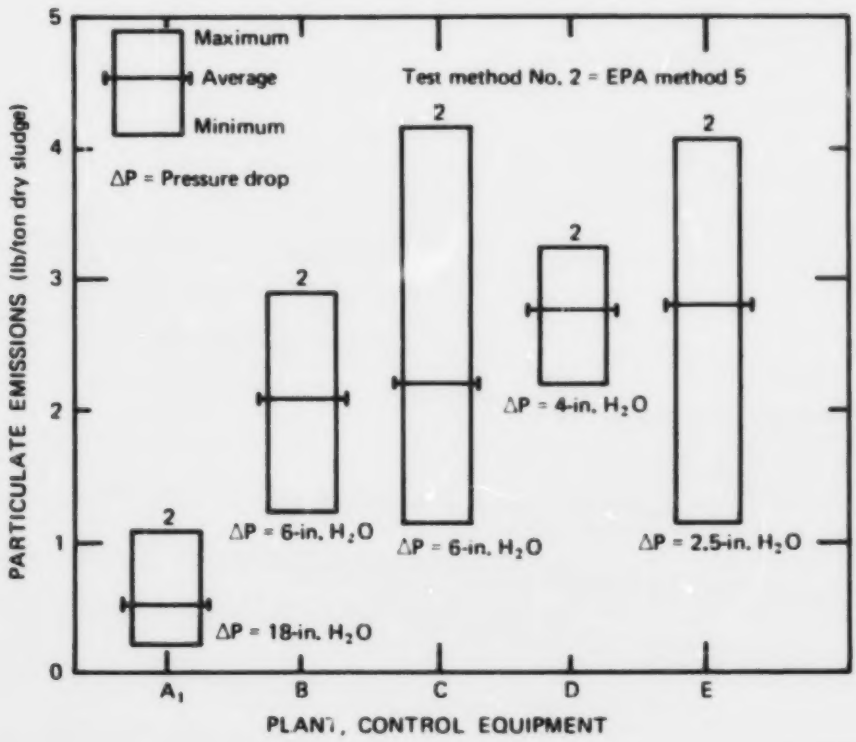

Figure 1. Particulate emissions from sludge incinerators at wastewater treatment plants. (See reference 4.)

METALS

Wastewater sludges contain metals that could be hazardous if discharged into the atmosphere. Unfortunately, there are very few data on the metals being discharged to the atmosphere from municipal sludge incineration. The forms in which metals are found in sludge will influence their behavior on incineration.[5] For example, if cadmium is present in the sludge in solution as cadmium chloride, it could volatilize upon incineration. If it is present as a precipitated hydroxide, it would probably decompose to the oxide, but would not volatilize at the temperatures of incineration. It is believed, however, that most of the hazardous or potentially hazardous metals, with the exception of mercury, will not disproportionately appear in stack gases because of volatilization, but will be converted to oxides and appear in the particulates removed by scrubbers or electrostatic precipitators and in the ash.

Some data are available on the discharge of manganese and nickel, which indicate the following emission rates from incinerator facilities with emission controls:

Metal	Emission factor range, millipounds per ton (dry solids)
Mn	0.5 to 1.6
Ni	.2 to 8.2

In both cases, the higher limit is represented by a single measurement.

Mercury is an example of a substance that presents special problems during incineration. High temperatures during incineration decompose mercury compounds to volatile mercuric oxide or metallic mercury.

Tests for mercury have been conducted by EPA[7] on 42 sewage treatment plant sludges. The mercury content ranged from 0.6 ppm to 43 ppm (in terms of dry solids) with an average value of 4.2 ppm. Tests on five incinerators equipped with scrubbers showed an average emission factor of 1.65 grams of mercury emitted to the atmosphere per metric ton of dry sludge incinerated. Mercury-removal efficiencies of water scrubbers varied from 68 to 96 percent. A study of the fate of mercury in municipal incineration plants has reported[8] that 9.7 percent of the mercury entering a multiple-hearth furnace at Palo Alto, Calif., escaped the wet scrubber and entered the atmosphere, 59 percent appeared in the furnace ash, and the remainder appeared in the scrubber underflow. In the same incinerator, only 0.84 percent of the lead in the sludge feed entered the atmosphere, with 88 percent in the ash and the rest in the scrubber underflow. The wet scrubber removed 93 percent of the lead and 76 percent of the mercury from the exhaust gases.

In accordance with Section 112 of the Clean Air Act Amendments of 1970, a national emission standard for mercury as a hazardous atmospheric pollutant resulting from sludge incineration was proposed on October 25, 1974. This proposed hazardous pollutant standard limits the atmospheric discharge of mercury from the incineration and drying of wastewater-treatment-plant sludges to a maximum of 3,200 g/d.[9] This limit is based on maintaining an average ambient mercury concentration of 1 $\mu g/m^3$ over a 30-day period. At an average emission rate (using wet scrubbers) of 1.65 grams of mercury per metric ton of dry solids incinerated, incineration facilities of 1,939 metric tons per day of dry solids (2,138 tons per day of dry solids) will approach this limit. There are, however, no known existing wastewater plants or new plants anticipated for use in the foreseeable future that will approach this size.

GASEOUS POLLUTANTS

Gaseous pollutants that could be released by sludge incineration are hydrogen chloride, sulfur dioxide, oxides of nitrogen, and carbon monoxide. Data are presented in tables 1-6 on the quantities of these materials found in stack gases. Carbon monoxide is no threat if the incinerator is properly designed and operated. Hydrogen chloride, which would be generated by decomposition of certain plastics, is not a significant problem at concentrations currently observed. Consideration of

the possibility of SO_2 and NO_x pollution is aided by examination of the sulfur and nitrogen content of sludges. Sulfur content is relatively low in most sludges. In addition, much of this sulfur is in the form of sulfate, which originated in the wastewater. Sulfur dioxide is not expected to be a serious problem. At San Mateo, Calif., the SO_2 discharge concentrations were found to be 10.2 ppm as compared to a 300-ppm standard.[10]

Sludge typically has a high nitrogen content from proteinaceous compounds and ammonium ion. Limited data are available for predicting whether a high proportion of these materials will be converted to oxides of nitrogen on combustion. From the data available, the concentration of oxides of nitrogen from sludge incineration should be less than 100 ppm from a properly operated incinerator, and were observed to be less than 10 ppm from facility A (table 1). Considering this low concentration, the production of oxides of nitrogen will probably not limit the use of incineration for disposing of sludge in most cases.

ORGANICS

In addition to the major air pollutants resulting from the burning of sludge, toxic substances can arise because of the content of pesticides or other organic compounds in the sludge. Unfortunately, very limited data are available on the concentrations of these materials in municipal sludges or their fate in an incinerator. Data reported by EPA,[5] in a random selection of sludges, showed the following levels of materials present in the raw sludges:

Compound	Range (ppm)
Aldrin	16 (in one sludge only)
Dieldrin	0.08 to 2.0
Chlordane	3.0 to 32
DDD	Not detected to 0.5
DDT	Not detected to 1.1
PCB's	Not detected to 105

Pesticide and polychlorinated-biphenyl (PCB) determinations were made on sludges collected during the incinerator tests at three of the five plants listed in tables 1-6.[5] PCB's were found in all of these sludges, but concentrations were low (1.2 to 2.5 ppm). Pesticides and PCB's were found only in the sludge. They were not found in the ash from either type incinerator, nor in the inlet or outlet scrubber water. Ash can be analyzed for these materials to the same degree of sensitivity as the sludge. A level of 0.1 μg/g (ppm) could easily have been detected. It is quite certain that these materials are not being carried out in the ash.

The mass flow rate of water to the scrubber is about 400 times the dry solids flow rate to the incinerator. Consequently, the concentration at which these materials can be detected in water must be sufficiently low to be sure that they are not escaping in the scrubber water. Fortunately, analytical techniques are such that these materials can be detected in water down to 0.1 ng/g (ppb). Thus, it is reasonable to believe that they are not in the scrubber water.

Since the PCB's do not appear in ash or scrubber water, they are either destroyed by incineration or remain as vapors in the water-scrubbed (and cooled) gas stream. All of these materials have some solubility in water, and it is likely that no trace would be present in the scrubber water. Conse-

quently, their escape as vapors from the incinerators seems unlikely. However, one should also examine the available data on the decomposition of PCB's and pesticides in other situations.

Rapid thermal degradation of most pesticides has been shown to begin at approximately 500° C with near total destruction at 900° C (1,652° F).[11,12] If these materials volatilize before burning, the use of afterburners on incinerators would be needed to provide complete destruction. One manufacturer of pesticides achieves near total destruction of pesticides in its multiple-hearth carbon regenerator by providing an afterburner using a 0.23-0.80-second retention time at 1,600° to 1,800° F.

The PCB's are even more thermally stable than most pesticides, as one would suspect. An incinerator at St. Louis, Mo., achieves total destruction of concentrated PCB's at 2,400° F with a retention time of 2.5 seconds. Experiments have shown, however, that 99 percent destruction is possible at 1,600° to 1,800° F in 2.0 seconds on pure PCB's.

Tests on municipal sludges[10] showed that total destruction of PCB was possible when oxidized in combination with sewage sludge and with an exhaust gas temperature of 1100° F versus 1600° F required when PCB's are handled separately. Ninety-five percent destruction of PCB's was achieved in a multiple-hearth furnace with no afterburning at the normal exhaust temperature of 700° F.

CONCLUSIONS

The EPA Sewage Sludge Incineration Task Force[5] concluded that it has been adequately demonstrated that existing well-designed and -operated municipal wastewater sludge incinerators are capable of meeting the most stringent particulate emission control regulation existing in any State or local control agency. This observation, coupled with the fact that the newly promulgated Federal NSPS are based on demonstrated performance of an operating facility, indicates that use of proper emission controls and proper operation of the incineration system will enable a facility to meet all existing particulate matter regulations. Although only the venturi scrubber (tables 1-6) met the promulgated standard in the EPA tests, EPA[4] has stated that—

> Impingement scrubbers tested by EPA did not meet the standard but, in our best judgment, would do so if used in conjunction with an oxygen meter that automatically regulates fuel burning rate. In our best judgment, electrostatic precipitators could also provide more than adequate control. There are no EPA test data on either of these control systems because during the test program there were no existing plants using them.

CASE HISTORIES

LIVERMORE, CALIF.

A recent evaluation[10] of the environmental impact of sludge incineration at Livermore, Calif., provides an interesting case history. Livermore proposed to install multiple-hearth furnaces for

sludge incineration and lime recalcining. Much of the offgas from the recalcining furnace will be recycled to the plant for recarbonation of the lime-treated wastewater. The Bay Area Air Pollution Control District (BAAPCD) adopted standards for discharge as shown in table 7. Also shown in table 7 are the results of analyses made at a nearby (San Mateo) multiple-hearth sludge incinerator. These test data and those presented in tables 2-6 indicate that little difficulty should be encountered in meeting particulate, hydrocarbon, and carbonyl standards with a properly designed and operated system. Of major interest in Livermore was the potential impact of NO_x, although there were no standards established. The relative contributions of NO_x in the Livermore valley from several sources were evaluated with the following results:

Source	Pounds NO_x per day
Automobiles	28,000
Sludge hauling	10
Sludge oxidation ...	50
Lime recalcining ...	12

The sludge-hauling value is only for the hauling of sludges to the border of the valley where it and the pesticides and PCB's it contains still must be dealt with in an environmentally acceptable fashion. In this example, the NO_x contribution from multiple-hearth incineration was slightly higher than the NO_x contribution from hauling only, but still was an insignificant fraction (0.2 percent) of the total NO_x discharge in the study area. The average per capita discharges of pollutants from automobiles and sludge incinerators were also calculated, and the results are shown in figures 2-4.

Table 7.–*Emission limits at Livermore, Calif.*

Test	Test results	Emission limits[1]
Hydrocarbons, C_2-C_6, ppm (dry basis) at 6 percent O_2	0.4 - 2.2	25
Total carbonyls, ppm (dry basis) at 6 percent O_2	3.4 - 7.6	25
Grain loading, gr/dscf[2] at 12 percent CO_2	0.017 - 0.021	0.15

[1] According to the California BAAPCD regulation 2 for units under 100 tons per day capacity with emissions adjusted to 6 percent O_2.

[2] dscf indicates dry standard cubic feet.

Source: F. P. Sebastian et al., "Sludge Incineration–Air Emission Standards vs. Technology–A Case Study," presented at Water and Wastewater Equipment Manufacturers Association Industrial Water and Pollution Conference and Exposition, Detroit, Mich., Apr. 1974.

PALO ALTO, CALIF.

Figure 5 illustrates the results obtained at Palo Alto, Calif., with a multiple-hearth furnace equipped with multiple-tray impingement scrubbers. Nitrous oxide emission at Palo Alto was only 0.037 g/day[10] as compared to 0.29 shown in figure 4 as a typical value. If this level of NO_x were achieved in the Livermore example discussed earlier, the NO_x discharge from incineration and recalcination would be even less than that from hauling alone.

REFERENCES

[1] "National Source Performance Standards, Municipal Incineration," *Fed. Reg.*, *36*, No. 247, 24876, Dec. 23, 1971.

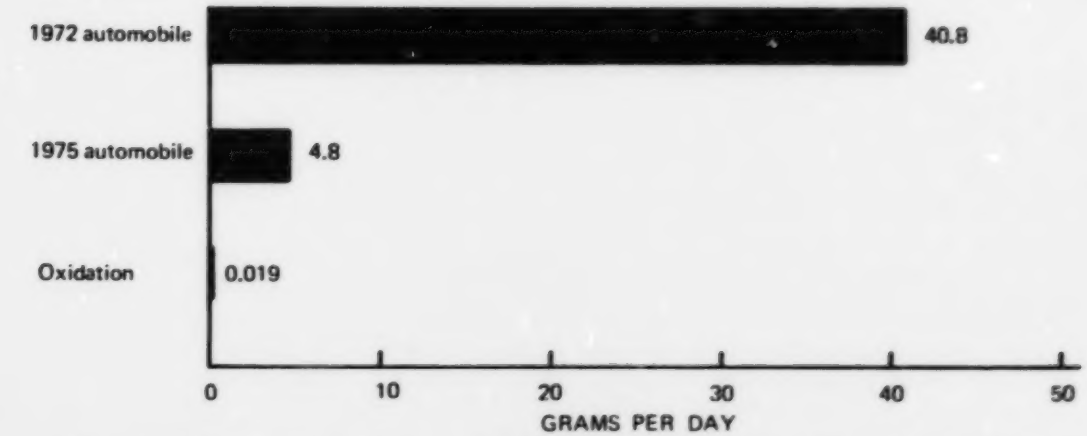

Figure 2. Relative per capita contributions of hydrocarbons from automobiles and sludge incineration. (See reference 10.)

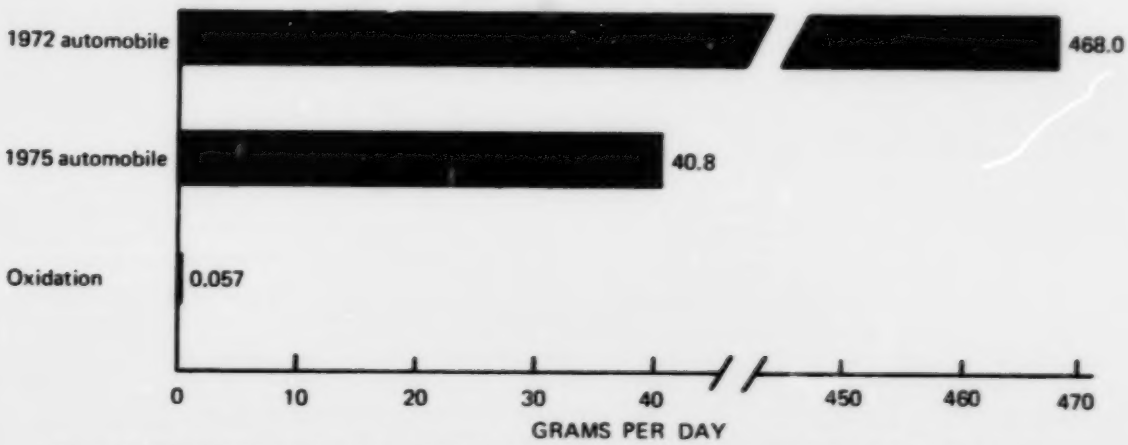

Figure 3. Relative per capita contributions of carbon monoxide from automobiles and sludge incineration. (See reference 10.)

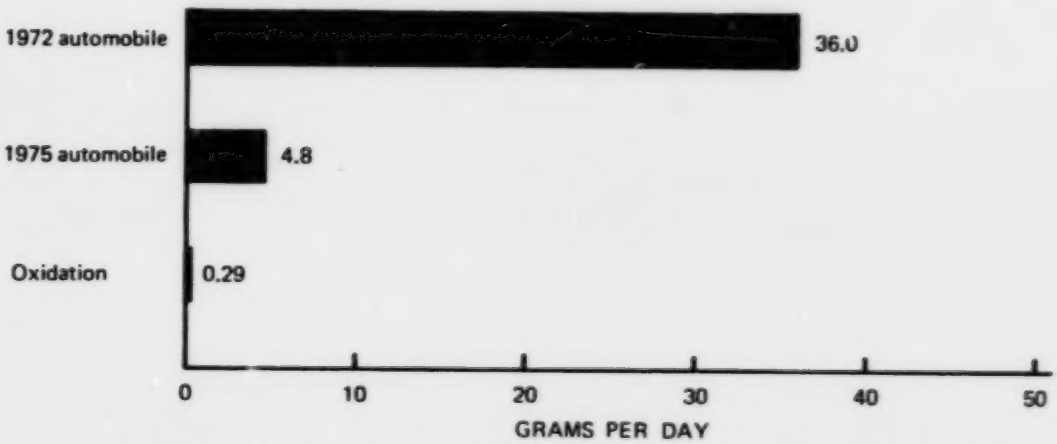

Figure 4. Relative per capita contributions of nitrogen oxides from automobiles and sludge incineration. (See reference 10.)

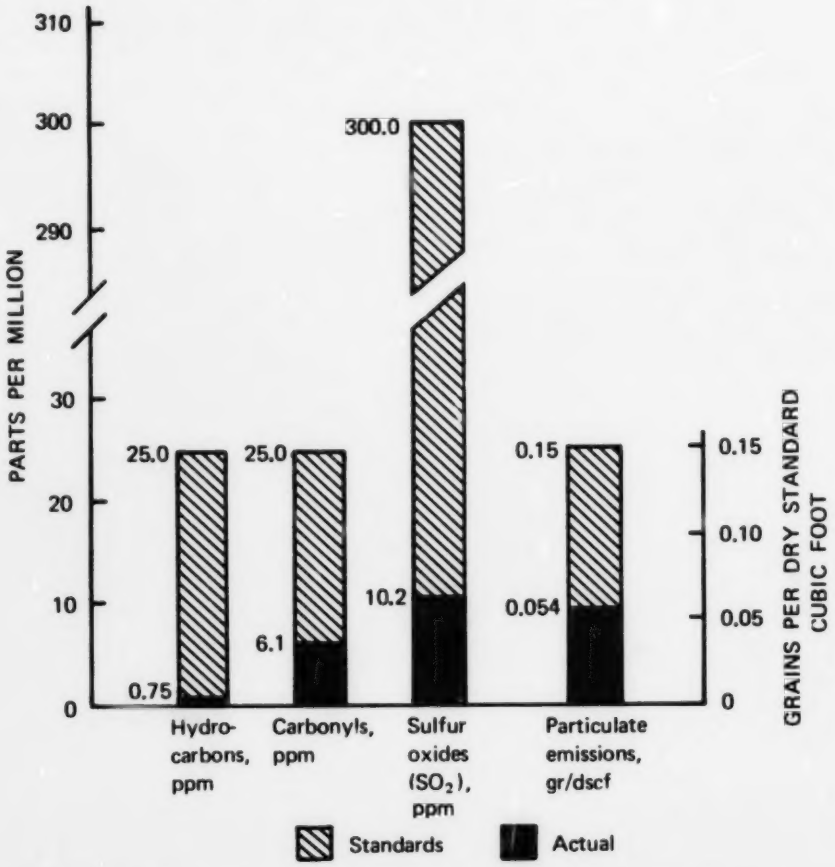

Figure 5. Standards and emissions from the Palo Alto multiple-hearth incinerator. (See reference 10.)

[2] S. Balakrishman, D. E. Williamson, and R. W. Okey, *State of the Art Review on Sludge Incineration Practice.* Federal Water Quality Administration Report 17070 olV 04/70, 1970.

[3] R. S. Burd, *A Study of Sludge Handling and Disposal.* Federal Water Pollution Control Administration Publication WP-20-4, May 1968.

[4] *Background Information for New Source Performance Standards,* EPA Report 450/2-74-003, APTD-1352C, Feb. 1974, vol. 3.

[5] Final report, "Sewage Sludge Incineration Task Force," EPA, Feb. 1970.

[6] *Background Information for Proposed New Source Performance Standards,* EPA Report APTD-13526, June 1973, vol. 2, appendix.

[7] *Background Information on National Emission Standards for Hazardous Air Pollutants—Proposed Amendments to Standards for Asbestos and Mercury,* EPA 450/2-74-009a, Oct. 1974.

[8] "A Study of Pesticide disposal in a Sewage Sludge Incinerator," Versar, Inc., Monthly progress report, EPA Contract No. 68-01-1587, Sept. 9, 1974.

[9] "Asbestos and Mercury—Proposed Amendments to National Emission Standards," *Fed. Reg.*, 39, No. 208, pt. 2, 38064, Oct. 25, 1974.

[10] F. P. Sebastian et al., "Sludge Incineration—Air Emission Standards vs. Technology—A Case Study," presented at Water and Wastewater Equipment Manufacturers Association Industrial Water and Pollution Conference and Exposition, Detroit, Mich., Apr. 1974.

[11] *Basic Research on Equipment and Methods for Decontamination and Disposal of Pesticides and Pesticide Containers*, annual report, USDA Grant No. 12-14-100-9182(34), Mississippi State University, June 1968 to June 1969.

[12] *Organic Pesticides and Pesticide Containers—A Study of Their Decontamination and Combustion*, Foster D. Snell, Inc., final report, Bureau of Solid Waste Management Contract No. CPA-69-140, 1970.

METRIC CONVERSION TABLES

Recommended Units

Description	Unit	Symbol	Comments	Customary Equivalents
Length	metre	m	*Basic SI unit*	39.37 in. = 3.28 ft = 1.09 yd
	kilometre	km		0.62 mi
	millimetre	mm		0.03937 in.
	micrometre	μm		$3.937 \times 10^{-5} = 10^{-3}$ A
Area	square metre	m^2		10.764 sq ft = 1.196 sq yd
	square kilometre	km^2		6.384 sq mi = 247 acres
	square millimetre	mm^2		0.00155 sq in.
	hectare	ha	The hectare (10 000 m^2) is a recognized multiple unit and will remain in international use.	2.471 acres
Volume	cubic metre	m^3		35.314 cu ft = 1.3079 cu yd
	litre	l	The litre is now recognized as the special name for the cubic decimetre.	1.057 qt = 0.264 gal = 0.81×10^{-4} acre-ft
Mass	kilogram	kg	*Basic SI unit*	2.205 lb
	gram	g		0.035 oz = 15.43 gr
	milligram	mg		0.01543 gr
	tonne or	t	1 tonne = 1 000 kg	0.984 ton (long) =
	megagram	Mg	1 Mg = 1 000 kg	1.1023 ton (short)
Time	second	s	*Basic SI unit*	
	day	d	Neither the day nor the year is an SI unit but both are important.	
	year	year		
Force	newton	N	The newton is that force that produces an acceleration of 1 m/s^2 in a mass of 1 kg.	0.22481 lb (weight) = 7.233 poundals
Moment or torque	newton metre	N-m	The metre is measured perpendicular to the line of action of the force N. Not a joule.	0.7375 ft-lbf
Stress	pascal	Pa		0.02089 lbf/sq ft
	kilopascal	kPa		0.14465 lbf/sq in

Recommended Units

Description	Unit	Symbol	Comments	Customary Equivalents
Velocity linear	metre per second	m/s		3.28 fps
	millimetre per second	mm/s		0.00328 fps
	kilometres per second	km/s		2.230 mph
angular	radians per second	rad/s		
Flow (volumetric)	cubic metre per second	m^3/s	Commonly called the cumec	15,850 gpm = 2.120 cfm
	litre per second	l/s		15.85 gpm
Viscosity	pascal second	Pa·s		0.00672 poundals/sq ft
Pressure	newton per square metre or pascal	N/m^2 Pa		0.000145 lb/sq in
	kilometre per square metre or kilopascal	kN/m^2 kPa		0.145 lb/sq in.
	bar	bar		14.5 lb/sq in.
Temperature	Kelvin	K	*Basic SI unit*	
	degree Celsius	C	The Kelvin and Celsius degrees are identical. The use of the Celsius scale is recommended as it is the former centigrade scale.	$\frac{5F}{9} - 17.77$
Work, energy, quantity of heat	joule	J	1 joule = 1 N-m where metres are measured along the line of action of force N.	2.778×10^{-7} kw hr = 3.725×10^{-7} hp-hr = 0.73756 ft-lb = 9.48×10^{-4} Btu
	kilojoule	kJ		2.778 kw-hr
Power	watt	W	1 watt = 1 J/s	
	kilowatt	kW		
	joule per second	J/s		

Application of Units

Description	Unit	Symbol	Comments	Customary Equivalents
Precipitation, run-off, evaporation	millimetre	mm	For meteorological purposes it may be convenient to measure precipitation in terms of mass/unit area (kg/m^2). 1 mm of rain = 1 kg/m^2	
River flow	cubic metre per second	m^3/s	Commonly called the cumec	35.314 cfs
Flow in pipes, conduits, channels, over weirs, pumping	cubic metre per second	m^3/s		
	litre per second	l/s		15.85 gpm
Discharges or abstractions, yields	cubic metre per day	m^3/d	1 l/s = 86.4 m^3/d	1.83×10^{-3} gpm
	cubic metre per year	m^3/year		
Usage of water	litre per person per day	l/person day		0.264 gcpd
Density	kilogram per cubic metre	kg/m^3	The density of water under standard conditions is 1 000 kg/m^3 or 1 000 g/l or 1 g/ml.	0.0624 lb/cu ft

Application of Units

Description	Unit	Symbol	Comments	Customary Equivalents
Concentration	milligram per litre	mg/l		1 ppm
BOD loading	kilogram per cubic metre per day	kg/m^3d		0.0624 lb/cu-ft day
Hydraulic load per unit area, e.g. filtration rates	cubic metre per square metre per day	m^3/m^2d	If this is converted to a velocity, it should be expressed in mm/s (1 mm/s = 86.4 m^3/m^2 day).	3.28 cu ft/sq ft
Hydraulic load per unit volume; e.g., biological filters, lagoons	cubic metre per cubic metre per day	m^3/m^3d		
Air supply	cubic metre or litre of free air per second	m^3/s l/s		
Pipes				
diameter	millimetre	mm		0.03937 in.
length	metre	m		39.37 in. = 3.28 ft
Optical units	lumen per square metre	lumen/m^2		0.092 ft candle/sq ft